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PRESSURE MEASUREMENTS DURING FLIGHT.

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By

A. Proll.

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The determination of the distribution of the lifting forces on a wing section and on the whole width of a supporting surface, concerns not simply the calculation of the strength of the cell, but is also very important from the aerodynamic standpoint, since it makes it possible to draw valuable conclusions concerning the action of the surface, its more or less favorable shape and also concerning the agreement of the theoretical and actual air flow. It has therefore long been sought to solve this problem by experimenting with models, as well as by many theoretical calculations. In passable agreement with these, so-called "normal cases" have been adopted, which represent possible flight conditions and typical unfavorable kinds of loading. In this connection, reference is made to the publications of the "Flugzeugmeisterei" (Air Service Administration), Technische Berichte, Vol. 1, p. 81.

In actual flight, these cases overlap more or less and it is quite conceivable that dangerous stresses may arise from especially unfavorable pressure distribution. Even the hitherto little regarded conditions in curved flight and the dynamic effects of squalls are often very important in strength problems. For investigating these effects, it is desirable to make the pressure measurements on the wing itself in a similar way to those made

* From "Zeitschrift für Flugtechnik und Motorluftschiffahrt," June 30, 1921, pp. 177-181.

on models. By means of small tubes, distributed over the entire wing and connected with recording pressure gages, diagrams are made of the pressures existing at every instant and with them the varying stresses on the airplane, which diagrams however now give a true record of the pressures occurring in actual flight, in contrast with the testing of only certain typical cases on models, provided possible sources of error are avoided (for instance, difference of pressure within the wing from that on the outside, too long tubes and the consequent damping and phase displacement of the indications of the instrument).

Experiments of this kind have been variously performed, with more or less successful results. Especially in England (Reports of the Advisory Committee of Aeronautics, 1921), many experiments have been made in this connection both during and since the War. In most cases, all the pressure tubes lead to liquid gages, mounted side by side on a board and whose position could be permanently registered by photography. Similar experiments on tail planes were carried out at the "Flugzeugmeisterei" by Everling (Flossendruckmessungen, Technische Berichte, Vol. 1, p. 302.)

When, in the following lines, mention is made of the first experiments undertaken by the Aeronautical Research Institute of the Hanover Technical High School, there will also be shown another, not unfavorable device, employed in the same connection. That, notwithstanding, it was impossible to obtain better results was due to the fact that when, after many difficulties, the experiments were well under way, all further activity had to be suspended, as a result of the flight prohibition by the Entente. Nevertheless a few experiments offer much of interest and consequently justify a short review.

A. General Arrangement.

The original idea was to record the air pressure on the spot, that is without long intervening tubes, by some simple automatic registering device. This was therefore made in such small dimensions that it could be inserted into the wing between the ribs and stand in direct connection with the pressure openings, as shown in Fig. 1.

The pressure recorders (Fig. 2) consisted, in the first experiments, of flat disks with thin rubber diaphragms and were differently constructed for increased and diminished pressure. Since the results, in spite of frequent adjustments, could not be considered free from error, the disks were afterwards made with thin corrugated metal covers. Special attention was given to the balancing of the recording stylus.

The holes were situated along a middle line on the upper wing in a broad ash strip, which replaced the fabric covering at this place. Comparative experiments were also tried with ring-shaped tubes, instead of simple ones (see below).

B. Preliminary Experiments for Determining the Best Location of the Pressure Gage.

Since it was not demonstrable off-hand that the air in the wings could not agree with the static pressure of the undisturbed surrounding air (on account of the greater or smaller permeability of the fabric, the openings, etc.), the pressure recorder was, in a few further comparative experiments, placed in an airtight screwed-on aluminum case, which was connected with the interior of the fuselage (observer's post) by a tube of 20 mm. diameter. Even here the surrounding pressure was not everywhere undisturbed, as was shown by the results of a few observations.

Experiment a.- Two pressure recorders in the wing, one open and the other covered in the above-mentioned manner. The requisite openings were located near one another on like section points on the lower side of the upper wing. The original diagrams (Figs 3 and 4) are practically the same, only the absolute deflections are smaller with the inclosed instrument, a like result being obtained in a second experiment, in which the pressure recorders had been exchanged. The open instrument always showed the greater pressure differences both on the pressure side (maximum 18 and 12 mm. water column) and on the suction side (-13 and -8 mm.) At first this created the impression that, with the inclosed instrument, the counterpressures were constantly displaced in the same direction against the external pressure, constituting a kind of damping effect. It was not possible however to confirm any inertia effect (phase displacement) in the inclosed instruments.

In another experiment of this nature, the same phenomenon was exhibited in still greater degree. There were far greater deflections of the open instrument, whereby, to be sure, the openings for the latter were located nearer the middle of the wing section, where the pressure increases rapidly.

Fig. 5 is also interesting. This was taken with the open pressure recorder on a flight in which curves were constantly flown during the ascent.

Experiment b.- In order to answer the question as to whether perhaps the long tube to the inclosed pressure recorder was to blame for the great differences (through some action on the principle of the variometer) an inclosed pressure recorder was suspended by spiral springs in the rear end of the fuselage and the 20 mm. again carried to the observer's post. The pressure opening to the diaphragm was closed air-tight. This was also the case with an open pressure recorder, which was suspended directly in the observer's cockpit. The pressure recorders should then have worked like barographs. There were however no deflections worth mentioning, probably due to leakiness of the diaphragms.

An explanation of all these phenomena was first obtained through experiment c. One pressure recorder was placed open in the wing, and the other open in the observer's cockpit, with the interpolation of a small pressure pipe from the tube, of 3.5 m. length and 2.7 mm. inside diameter, the tube openings of both instruments being close together. The open instrument, located in the wing, again gave far greater pressure differences (Figs. 6 and 7).*

Since no inertia effect of the outer air can here enter into the question, the cause of the differences observed under a and b was immediately explained. The instrument in the wing is, in fact, on account of the leaky wing covering, holes, etc., under a very difficultly controlled counter-pressure which, in nearly all cases, is smaller than the undisturbed static air pressure and

* The suction effect on the lower side of the wing, which was noticeable in the instrument in the wing with the strong lift before landing, was not shown at all in the other pressure recorder.

hence gives greater deflections of the increased pressure recorder. (On the other hand, the condition mentioned under a, that the suction pressures of the inclosed instrument are smaller than those of the open instrument, is probably due to the fact that there is a still more reduced pressure in the long tube or in the observer's cockpit, than in the wing))

C. Experiments on the Influence of Long Pressure Tubes.

Before bringing the pressure recorder into the observer's cockpit, it was first necessary to determine how far the long small tube from the cone would influence the pressure readings, especially for sudden pressure changes. Two pressure recorders were compared in the laboratory, one with a very short direct connection, and the other with a 6 m. aluminum tube of 2.7 mm. diameter. The pressures, measured with a manometer, could be changed very rapidly, without showing any phase displacement on the two pressure recorders and with scarcely any diminution in the deflections of the second instrument.

The pressure recorder could accordingly be placed unhesitatingly in the observer's cockpit, which considerably facilitated its management and first made its adjustment possible during flight. For the further experiments, the ten holes (5 on top and 5 on the bottom of the wing), as shown in Fig. 12, were added, with the tubes leading to the pressure recorders. The latter were arranged over and near one another in a frame on the left side of the observer's seat, whereby however the existing pressure differences in the different parts of the observation space could not be taken into account. The space however was so much reduced by the fixtures and by the observer himself, that dynamic pressure differences could hardly be generated in the narrow intervening spaces.

D. Experiments with Different Entrance Tubes.

The air openings ordinarily employed in the wing are 2 mm. holes in small round steel plates, which are set into the ash strip on the wing. Although the edges of the holes were rounded, there was still the conjecture that local dynamic pressures might be generated by these edges and accordingly tubes with ring-shaped opening (4 mm. diameter, 3/4 mm. wide) were sought. The results were however the same throughout, on which account the simple holes were considered sufficient.

E. Provisional Results of Pressure Measurements.

Simultaneously with the pressure recorders which were installed in the above-described manner in the observer's cockpit,* the flight speed was recorded by an "Atmos" speed recorder (Fig. 9) and likewise the longitudinal dip of the fuselage axis (Fig. 10) by means of a pendulum inclinometer with recording device. The readings of the latter instrument, which was provided with oil damping, could naturally hold good to only a certain extent for the permanent condition. A correction could be estimated for other conditions.** The speed could also be corroborated by a

* The experiments were made on an old airplane of the "Hannoversche Waggonfabrik," Type Han C. L II, (185 HP Opel Argus engine.

** The motion of the large drum of the pendulum recorder was considerably disturbed by the vibrations, for which reason the marks in Fig. 10 do not entirely agree, in point of time, with those in the other figures.

Morell anemotachometer.

Table.

Point No.	Time min.	Height m.	Speed m/s v	Dip of fuselage: Read Φ'	Dip of fuselage: Corrected Φ *	Climbing Speed m/s	Angle of climb β	Angle of attack α
1	1.3	100	31	7°	5°	1.6	3°	7°
2	4	300	33	4°	$3\ 1/4^\circ$	1.4	$2\ 1/2^\circ$	$5\ 3/4^\circ$
3	5	350	36	2°	2°	0.9	$1\ 3/4^\circ$	$5\ 1/4^\circ$
4	8	300	42	-9.5°	-9.5°	-4.2	-5.6°	1°
6	12	375	38	$3/4^\circ$	$3/4^\circ$	0.7	$1\ 1/4^\circ$	$4\ 1.2^\circ$
7	13	300	47	-13°	-12°	-5.5	$-6\ 3/4^\circ$	$-1/4^\circ$

Mean incidence of wing to fuselage axis $x = 5^\circ$

$$\alpha = x + \Phi - \beta$$

In the table and diagrams (Figs. 8-12) the numerical values of one of the preliminary experiments are given, whereby the corresponding points in all the diagrams are indicated by the numbers 1 to 7. Since all the instruments had not yet worked perfectly, the results of these flights can make no claim to special trustworthiness. Namely, in the data on gliding flights (which were continued all too short a time for obtaining a permanent status) we can obtain only a very incomplete conception of the actual phenomena. The experiments described were considered only as preliminary experiments and were simply for the purpose of testing the accuracy of the many instruments. On this account, the flights were not carried further, especially not to great heights. It was intended, however, to undertake a series of systematic flights, but the increasingly difficult conditions and the flight prohibition by the Entente brought the experiments to a premature end.

* The correction is made with reference to the acceleration condition of the airplane, which may be estimated from the speed diagram.

Later, when it was again possible to make a short flight, a second speed recorder was employed, according to the specifications of Dr. Wieselsberger of the Göttingen Aerodynamic Institute, with very favorable results. (See "Zeitschrift fur Flugtechnik und Motorluftschiffahrt," for January, 1921, p.4.) The pressure measurements led to results similar to those previously obtained, for which reason they are omitted here.

From the results of the pressure measurements, as given in the table, the temporary pressure changes at the different openings could be graphically represented. They indicate clearly the various flight conditions. It is however noticeable, that apparently the increased pressure effect is much greater than the suction effect, which does not agree at all with the known Eiffel, Göttingen and other experiments.

Lastly, Fig. 12 shows the pressure distribution curves, along the wing section, Göttingen measurements, T.B., section No. 212, for slightly ascending flight (experimental point No. 3 in the table). Here it is most noticeable that the point of greatest pressure, according to the experiments, hole No. 2) lies comparatively far back of the leading edge. This may perhpps be explained by the fact that the greatest dynamic pressure lies between holes 1 and 2, somewhat as shown by the extrapolated curve (dashed). It was also intended to put more holes in the front part of the wing, which (for reasons already mentioned) could not however be carried out. Even the pressure distribution in the immediate vicinity of the leading edge was left undetermined and it would be wrong anyway to draw general conclusions from these measurements, since they were only undertaken to illustrate the methods.

In general, it may be said that, by further patient and careful experimenting with the described method of pressure measurement, surely just as good and, above all, more readily surveyed results may be obtained, than by the manometer method, and it will therefore be welcome, if a resumption of these experiments should be rendered possible in the near future.

Translated by the National Advisory Committee for Aeronautics.